Summary of Methods for Control of Aquatic Invasive and Nuisance Plants with Special Emphasis on Eurasian Watermilfoil (*Myrophillum spicatum*) and Curly-leaf Pondweed (*Potamogeton crispus*)

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Table of Contents

Table of Contents (cont.)

Section **Page**

List of Tables

List of Abbreviations and Acronyms

2,4-D	2,4-dichlorophenoxyacetic
BMP	Best Management Practice
Ecology	Washington Department of Ecology
IPM	Integrated pest management
µg/L	micrograms per liter
mg/L	milligrams per liter
n.d.	no date
NYCRR	New York Codes, Rules and Regulations
NYSDEC	New York State Department of Environmental Conservation
NYSFOLA	New York State Federation of Lake Associations
ppb	parts per billion
ppm	parts per million
spp.	several species
USEPA	United States Environmental Protection Agency
WDNR	Wisconsin Department of Natural Resources

Executive Summary

Aquatic plant management tools and techniques are classified as physical, chemical, or biological. All of these tools and techniques come with advantages and disadvantages and have environmental impact. Management approaches should be selected based upon waterbody-specific economic, environmental, and technical constraints, and should fit the site-specific management goals (Madsen 2000). There are two highly invasive, non-native, aquatic plant species currently found in Chautauqua Lake: Eurasian watermilfoil (*Myriophyllum spicatum*) and curly-leaf pondweed (*Potamogeton cripsus*) (Racine-Johnson Aquatic Ecologists 2017, SOLitude Lake Management 2017). Eurasian watermilfoil was first documented in the lake in 1972 and curly-leaf pondweed was first documented in the lake in 1937 (Racine-Johnson Aquatic Ecologists 2018). Along with these invasive species, aquatic plant growth is prolific – to nuisance levels - in the littoral zone across various areas in the lake.

This white paper provides an overview of available aquatic plant management techniques, with emphasis on herbicides available in New York State for use on submerged nuisance aquatic plant species, including Eurasian watermilfoil and curly-leaf pondweed. These herbicides are: copper, diquat, endothall, florpyrauxifen-benzyl, flumioxazin, fluridone, imazamox, triclopyr, and 2,4-dichlorophenoxyacetic acid (2,4-D). Summary information for each of these herbicides is provided in Table ES-1. Diquat, endothall, fluridone, and 2,4-D have been in use for several decades, and their behavior in the environment and effects on target and non-target species are well understood (Hussner et al. 2016). Best Management Practices that can be applied to the control of aquatic invasive plant species include: (1) regularly monitoring plant communities to track herbicide efficacy and plant regrowth to better inform management decisions (i.e., adaptive management) (Thum et al. 2017); (2) utilizing the most effective combinations of available physical, chemical, and biological management techniques and tools available (i.e., integrated plant management) (Ecology 2017; New York State Federation of Lake Associations 2009); and (3) rotating herbicides used at a given site to prevent herbicide resistance in target plant species (Aquatic Plant Management Society 2014; Hussner et al. 2016). Based upon the information reviewed, herbicides can be a selective and effective management technique for the control of Eurasian watermilfoil and curly-leaf pondweed, and other nuisance aquatic plants. If used in conjunction with other non-chemical techniques, a rotation of several herbicides would be an effective management strategy for controlling these two invasive plant species.

For larger scale applications, a rotation of selective, systemic herbicides (e.g., florpyrauxifen-benzyl, imazamox, triclopyr, and 2,4-D) would lead to the least impacts to non-target aquatic plant species and aquatic fauna and effectively control Eurasian watermilfoil. Since these systemic herbicides are not as effective on curly-leaf pondweed, spot treatments with contact, broad-spectrum herbicides (e.g., endothall and flumioxazin) in vegetative beds with high density of curly-leaf pondweed would effectively control this invasive species with some impacts to native pondweeds.

Table ES-1 Summary of pertinent information for select herbicides available in New York State for control of submerged invasive aquatic plants

	Copper	Diquat	Endothall	Florpyrauxifen-benzyl	Flumioxazin	Fluridone	Imazamox	Triclopyr	2,4-D
Primary Use									
Susceptible aquatic plant groups	Submerged Floating	Submerged Floating Emergent	Submerged Floating	Submerged	Submerged Floating Emergent	Submerged Floating	Submerged Floating Emergent	Submerged Floating Emergent	Submerged Floating Emergent
Mode of Action									
	Contact. Broad spectrum. Plant cell toxicant.	Contact. Broad spectrum. Inhibits photosynthesis and destroys cell membranes.	Contact. Broad spectrum. Inhibits respiration and protein synthesis.	Systemic. Selective. Causes excessive elongation of plant cells, leading to atypical growth and fragility of leaf and shoot tissue.	Contact. Broad-spectrum. Inhibits plant-specific enzyme (polyphenol oxidase); causes rapid desiccation and necrosis.	Systemic. Broad spectrum. Disrupts carotenoid synthesis causing bleaching of chlorophyll.	Systemic. Inhibits plant-specific enzyme acetolactate synthase. New growth stunted.	Systemic. Selective to dicots. Auxin mimic, plant growth regulator.	Systemic. Selective to dicots. Auxin mimic, plant growth regulator.
Fate in Aquatic Systems									
Typical Half-life	Hours to 1+ days	½ to 7 days	2 to 14+ days	<1 to 6 days	Minutes to 1+ day	45+ days	14+ days	4 to 14+ days	4 to 21+ days
Degradation Pathway(s)	Does not degrade. Binds to ligands in water column or sediment.	Adsorption. Photolysis. Microbial degradation. Binds to negatively charged particles in water column.	Microbial degradation.	Photolysis. Aerobic aquatic degradation. Hydrolysis.	Hydrolysis.	Photolysis. Microbial degradation. Adsorption.	Photolysis. Microbial degradation.	Photolysis. Microbial degradation.	Microbial degradation. Photolysis Plant metabolism.
Relative Effectiveness									
General Exposure Requirements	Hours to 1+ day.	Hours to days.	Hours to days.	12 to 72 hours.	Hours to 1+ day.	45+ days.	14+ days.	Hours to days.	Hours to days.
Response Time	7 to10 days or up to 4 to 6 weeks.	7 days.	7 to14 days.	2 to 3 weeks.	Rapid, similar to other contact herbicides.	30-to 90 days.	4 to 12 weeks.	5 to 7 days, up to 2 weeks.	5 to7 days, up to 2 weeks.
Where Effective	High water exchange areas.	Shorelines, spot treatments, high water exchange areas.	Shorelines, spot treatments, high water exchange areas.	Slow-moving waterbodies including ponds, lakes, and reservoirs.	Waterbodies with pH less than 8.	Small lakes, slow flowing systems.	Ponds, lakes, reservoirs, and other slow moving or quiescent bodies of water.	Lakes and slow-flow areas.	Lakes and slow-flow areas.
Curly-leafed pondweed (*Potamogeton crispus*)	Effective.	Effective.	Effective.	--	Effective.	Effective.	Effective.	Not Effective.	Not Effective.
Eurasian watermilfoil (*Myriophyllum spicatum*)	Effective.	Effective.	Effective.	Effective.	Effective.	Effective.	Effective.	Effective.	Effective.

Table ES-1 Summary of pertinent information for select herbicides available in New York State for control of submerged invasive aquatic plants

	Copper	Diquat	Endothall	Florpyrauxifen-benzyl	Flumioxazin	Fluridone	Imazamox	Triclopyr	2,4-D
Potential Impacts to Non-Target Aquatic Plant Species									
	Native pondweeds (*Potamogeton* spp.).	Not selective; effects wide variety of species.	Coontail (*Ceratophyllum demersum*), native pondweeds.	--	Spatterdock (*Nuphar* sp.), water lily (*Nymphaea* sp.), American lotus (*Nelumbo lutea*), coontail, duckweed (*Lemna* spp.), fanwort (*Cabomba caroliniana*), native pondweeds, native milfoils (*Myriophyllum* spp.).	Water hyacinth (*Eichhornia crassipes*), water lilies, bladderworts (*Utricularia* spp.).	Native pondweeds, pickerelweed (*Pontederia cordata*), arrowhead (*Sagittaria* spp.), bulrush (Cyperaceae), and cattails (*Typha* spp.).	*Phragmites*, arrowhead, water hyacinth, American frogsbit (*Limnobium spongia*), and water stargrass (*Heteranthera dubia*).	Coontail and water hyacinth.
Additional Advantages									
	Inexpensive. Rapid action. Approved for drinking water	Rapid action. Limited drift.	Rapid action. Limited drift.	Has *Reduced Risk* status based on the environmental and toxicological profiles as compared to currently registered herbicides. No restrictions for recreational uses or setback requirements for potable water intakes as long as within NYSDEC water quality standards for drinking water (50 µg/L). Nearly non-toxic to birds, mammals, and fish species. New mode of action, which can help prevent development of herbicide resistance.	Low potential to contaminate/ pollute the environment or cause non-target toxicity.	Very low dosage required. Few label restrictions	No use restrictions for livestock watering, swimming, fishing, domestic use, or use of treated water for agricultural sprays.	Slightly to practically nontoxic to aquatic fauna. No or limited (6 hour) use restriction for recreational uses, fishing, fish consumption, and livestock watering. May effectively control target species for more than one season.	Inexpensive.

Table ES-1 Summary of pertinent information for select herbicides available in New York State for control of submerged invasive aquatic plants

	Copper	Diquat	Endothall	Florpyrauxifen-benzyl	Flumioxazin	Fluridone	Imazamox	Triclopyr	2,4-D
Additional Disadvantages									
	Not biodegradable. Can be toxic to aquatic fauna depending on concentration, formulation, and ambient water chemistry. Ineffective at colder temperatures.	Sometimes toxic to zooplankton at recommended dosage. Inactivated by suspended particles (i.e. ineffective in turbid waters). Use restrictions for water supply, agriculture, and contact recreation.	May be toxic to aquatic fauna. Use restrictions for water supply, agriculture, and contact recreation.	Restrictions on the use of treated water for irrigation and watering livestock. Has been only tested against a selection of native aquatic plant species to date. Cannot exceed 50 ppb at potable water intakes.	May be toxic to aquatic fauna. Five day use restriction for irrigation on food crops.	Extremely soluble and mixable- difficult to perform partial lake treatment.	Use restrictions for irrigation. Cannot exceed 50 ppb at potable water intakes. There has been limited use in New York to date.	Use restriction for fish consumption, water supply, agriculture, and contact recreation. In deeper or turbid waters, triclopyr can persist at concentrations greater than 1 ppb for an extended period of time and may be carried downstream at concentrations greater than 1 ppb. More expensive than other herbicides.	Public perception. Varying toxicity to aquatic fauna depending on formulation and ambient water chemistry. Use restrictions for water supply, agriculture, and contact recreation.

Adapted from: AECOM, Inc. 2009, Cooke et al. 2005, Ecology 2017, Heilman and Getsinger 2018, Holdren et al. 2001, Hussner et al. 2016, Invasive Species Program 2018, Madsen 2014, Netherland 2014, NYSDEC 2019, NYSFOLA 2009, WDNR 2012a, 2012b, 2018a, 2018b, Woolf 2014,

Key:
-- = Data not available
NYSDEC = New York State Department of Environmental Conservation________;

1 Introduction

The white paper summarizes information regarding herbicides registered in New York State for use on submergent aquatic vegetation, with particular emphasis placed upon effectiveness on Eurasian watermilfoil (*Myriophyllum spicatum*) and curly-leaf pondweed (*Potamogeton crispus*). Material reviewed in the course of writing this document included peer-reviewed papers, environmental impact statements, textbooks, herbicide product labels (obtained from the New York State Department of Environmental Conservation [NYSDEC] Bureau of Pest Management Information Portal), and management guides and guidelines prepared by the North American Lake Management Society, Terrene Institute, the New York State Federation of Lake Associations (NYSFOLA), and the NYSDEC.

2 Aquatic Invasive Plants in Chautauqua Lake

The two highly invasive, non-native, aquatic plant species currently found in Chautauqua Lake are Eurasian watermilfoil and curly-leaf pondweed (Racine-Johnson Aquatic Ecologists 2017; SOLitude Lake Management 2017). Eurasian watermilfoil was first documented in the lake in 1972 and curly-leaf pondweed was first documented in the lake in 1937 (Racine-Johnson Aquatic Ecologists 2018). Other non-native aquatic plant species documented in Chautauqua Lake include: water chestnut (*Trappa natans*) in 2013; minor naiad (*Najas minor*) between 2003 to 2008 and in 2015; and starry stonewort (*Nitellopsis obtusa*) between 2009 and 2013, and in 2015 and 2016 (Racine-Johnson Aquatic Ecologists 2018). Although observed in Chautauqua Lake in some years, water chestnut, minor naiad, and starry stonewort have not spread extensively and become a nuisance.

A total of 51 aquatic plant species have been identified in Chautauqua Lake since 1937 (Racine-Johnson Aquatic Ecologists 2018). During the most recent, publicly available, lake-wide plant surveys of the littoral zone, 24 species were observed (Racine-Johnson Aquatic Ecologists 2017, 2018). While much of the diversity of the plant community is attributed to native species, plant abundance is dominated by Eurasian watermilfoil and curly-leaf pondweed (Racine-Johnson Aquatic Ecologists 2018). These two most recent surveys were conducted using the line intercept method (Madsen 1999).

3 Selection and Appropriate Use of Management Tools in Invasive Species Management

All available aquatic plant management tools and techniques come with advantages and disadvantages, and all have some environmental impact. The appropriate tools and techniques for a waterbody should be selected based upon waterbody-specific economic, environmental, and technical constraints, and should fit the site-specific management goals (Madsen 2000).

3.1 Available Management Tools

3.1.1 Physical

Physical techniques for macrophyte removal include (Holdren et al. 2001):

- "Mowing the lawn" (mechanized cutting or harvesting, weed rolling);
- "Tilling the soil" (rototilling or hydroraking);
- "Weeding the garden" (hand harvesting, suction harvesting, other manual techniques);
- Dredging;
- Water level control; and
- Benthic barriers.

Mechanical cutting and harvesting usually needs to be repeated more than once per year and can balance habitat, recreational, and other public use needs. Depending upon the method used, mechanical harvesting is non-selective, may result in direct impacts to aquatic fauna, and has the possibility of spreading invasive plant species through fragmentation (Holdren et al 2001). Aquatic plant species like Eurasian watermilfoil that grow rapidly and regenerate from fragments have a competitive advantage under a harvesting regime (Cooke et al. 2005). If timed well, laboratory studies and field observations have found that harvesting curly-leaf pondweed was effective at controlling regrowth (Cooke et al. 2005).

Rototilling and hydroraking are effective at destroying entire plants, but have the same disadvantages associated with mechanical cutting and harvesting and may also cause increased turbidity (Holdren et al. 2001).

Hand harvesting techniques are highly selective and may avoid some of the disadvantages associated with mechanical harvesting but are typically labor intensive and may also need to be repeated more than once per year (Holdren et al. 2001).

Dredging is an effective control for excessive sediment bound nutrients and vegetation; however, this technique is non-selective and removes all plants in the treated area (NYSFOLA 2009).

Water level control can be an effective option in waterbodies with the capability to draw down in the winter. Lowering the lake level over the winter allows the exposed sediments to freeze, causing the greatest impacts to submergent species with vegetative propagation (Holdren et al. 2001). Winter water level drawn downs have been found to effectively control milfoil species and enhance pondweed species (Holdren et al. 2001; NYSFOLA 2009). This technique may also impact neighboring wetlands and shorelines (NYSFOLA 2009).

Benthic barriers physically block light from reaching the lake bed in the littoral zone, thereby limiting rooted aquatic plant growth (NYSFOLA 2009). This technique can be effectively used in areas too shallow for more mechanized machinery (Cooke et al. 2005). Depending on size and placement specifics, use of benthic barriers can be a selective method for aquatic plant control, but they require more maintenance than other methods (NYSFOLA 2009).

3.1.2 Chemical

Herbicides are categorized as broad or selective, and contact or systemic.

Broad-spectrum herbicides control all or most of the vegetation they contact. Selective herbicides effect plants based on how each species responds to the herbicide. Dosage and timing of the application within target species growth cycles can impact the selectivity of an herbicide (Cooke et al. 2005).

Contact herbicides have quick results that typically have lasting effectiveness for several weeks to several months (Cooke et al. 2005; NYSFOLA 2009). These herbicides impact the plant biomass they come into contact with and are not translocated throughout the plant (Cooke et al. 2005; Madsen 2000; Netherland 2014; NYSDEC 2015; NYSFOLA 2009). Contact herbicides are considered more effective on annual plants, old and slow growing plants, and senescent plants (Cooke et al. 2005). In order to effectively control submersed weeds, contact herbicides must remain in the water column at the treatment area for a up to a few days (Netherland 2014).

Systemic herbicides are taken up by plant tissue and translocated to critical growth points within the plants, which makes them more selective and slower acting than contact herbicides (Cooke et al. 2005; Madsen 2000; Netherland 2014; NYSDEC 2015; NYSFOLA 2009). It typically takes three to eight weeks before results are observed, but control may last for several years (NYSFOLA 2009). Systemic herbicides are considered more effective on perennial and woody plants

(Cooke et al. 2005). If applied at a higher dosage than indicated on the product label, these types of herbicides may act like contact herbicides (Cooke et al. 2005; Madsen 2000).

It is considered a Best Management Practice (BMP) to rotate the herbicides used at a given site, as overreliance on herbicides with a single mode of action leads to resistance (Hussner et al. 2016). If used in accordance with the product label, herbicides have fewer environmental impacts than mechanical cutting and harvesting and are more cost-effective than other aquatic plant management techniques (Hussner et al. 2016; Netherland 2014).

A number of the herbicides discussed in Section 3.2, including diquat, endothall, fluridone, and 2,4-dichlorophenoxyacetic (2,4-D) acid, have been in use for several decades. As a result, their behavior in the environment and effects on target and non-target species is well understood (Hussner et al. 2016).

Compared with Eurasian watermilfoil, there are fewer herbicides available that specifically target curly-leaf pondweed control and none that offer selective removal of the plant (and not other native pondweeds) (Madsen et al. 2015).

3.1.3 Biological

Biological plant control techniques involve the introduction of fish, insects, and/or pathogens that negatively impact the target plant species (Holdren et al. 2001). This method may effectively provide control across multiple years but may cause unintended impacts to other species and the ecology of the waterbody (Holdren et al. 2001). Fish introductions may control more than the target species and may not control the desired plant species (Holdren et al. 2001; NYSFOLA 2009), while insect introductions in waterbodies abundant with Eurasian watermilfoil have not been found to be effective as a singular management technique (NYSFOLA 2009).

3.2 Available Herbicides for the Control of Eurasian Watermilfoil and Curly-leaf Pondweed

The following discussion pertains to herbicides registered in New York State for use on submergent aquatic vegetation, as the two aquatic invasive plant species of concern in Chautauqua Lake are both submerged aquatic plant species. These herbicides include: copper, diquat, endothall, florpyrauxifen-benzyl, flumioxazin, fluridone, imazamox, triclopyr, and 2,4-D. Glyphosate, another herbicide registered for use in New York State, is not included as it is registered for use on emergent and floating aquatic vegetation.

In New York State, use restrictions for several of the following herbicides are promulgated in the New York Codes, Rules and Regulations (NYCRR). These use restrictions are included in the following discussion.

3.2.1 Copper

Copper compounds are primarily used as algaecides and are sometimes added to other broad spectrum herbicide formulations (Holdren et al. 2001). Copper sulfate, which is ionic, is used as an algaecide. Chelated copper compounds, which are nonpolar, may be used as herbicides (NYSDEC 2015). Chelated copper compounds often used as herbicides for aquatic plants include ethylenediamine complexes, mixed ethanolamine complexes, triethanolamine complexes of copper, and similar active ingredient formulations (NYSDEC 2015).

While the use of copper sulfate for control of algae is addressed in the 6 NYCRR Part 327.6 (a), the use of chelated copper compounds to control algae and aquatic plants is not.

Under 6 NYCRR Part 703.5, there is also a potable water use restriction standard of 200 µg/L established for dissolved copper in waterbodies used as potable water sources (Class AA or Class A waterbodies) and for waterbodies upstream of potable water supplies (NYSDEC 2015). Chautauqua Lake is classified as a Class A waterbody (6 NYCRR Part 800.9 Table VI).

3.2.1.1 Mode of Action

Chelated copper compounds are contact herbicides that result in plant cell toxicity (Cooke et al. 2005; Netherland 2014).

3.2.1.2 Environmental Behavior and Fate in Aquatic Systems

Copper does not biodegrade. Instead, it binds to ligands in the water column or sediments, becoming biologically inactive, typically within hours to one day after application (Netherland 2014).

3.2.1.3 Relative Effectiveness, Typical Application Rates, and Timing of Application

Copper compounds are effective as herbicides in areas of high water exchange (Cooke et al. 2005; Madsen 2000).

Effective dosages typically range from 0.2 to 1.0 milligrams per liter (mg/L) (Netherland 2014). Copper compounds have a very short exposure requirement, typically 18 to 72 hours (Cooke et al. 2005; Madsen 2000; Netherland 2014).

In a tank study, Turnage and Madsen (2017) found that copper (ethylenediamine) alone, as well as in in tank mixtures with endothall, is a viable control for curly-leaf pondweed and turion production. Copper complexes have also been effective at controlling Eurasian watermilfoil (Texas A&M n.d.).

3.2.1.4 Potential Impacts to Non-Target Aquatic Plant Species

Since chelated copper compounds are nonpolar, they easily pass through plant membranes where they trigger a toxic effect and are less likely to bind to the gills of aquatic fauna (NYSDEC 2015).

Damage to native species, except for native pondweeds, is expected to be minimal as many submersed aquatic plant species are tolerant to copper-based herbicides (Vencill 2002, as cited in Turnage and Madsen 2017).

3.2.1.5 Additional Pros and Cons

Pros

- There are no restrictions on the use of copper in potable waterbodies or for irrigation water (Cooke et al. 2005; Madsen 2000; Netherland 2014).
- Inexpensive herbicide option (Cooke et al. 2005; Madsen 2000).
- Rapid action (Cooke et al. 2005)
- Toxic effects on fish observed in laboratory experiments can be mitigated by the presence of organic and inorganic ligands (e.g., carbonate ions) present in the water column (NYSDEC 2015).

Cons

- The effectiveness of copper compounds is dependent upon the chemical characteristics of the receiving waterbody; hard water can reduce the effectiveness of copper compounds as an herbicide (Netherland 2014).
- Regular application of copper can result in elevated concentrations of copper in sediments (Netherland 2014).
- Not biodegradable (Cooke et al. 2005; Holdren et al. 2001)
- Can be toxic to aquatic fauna depending on concentration, formulation, and ambient water chemistry (Holdren et al. 2001)
- Ineffective at colder temperatures (Holdren et al. 2001)

3.2.2 Diquat

Diquat dibromide is the active ingredient in multiple formulations registered for use in New York State, including Dibrox™, Diquat SPC 2L, Littora®, Harvester®, Reward®, Tribune™, and Verdure-X-Herbicide.

The following restrictions for diquat use for control of aquatic plants in New York state are presented in 6 NYCRR Part 327.6(b):

- Purpose: Authorized for the control of emergent plants having leafy growth lying flat on the water surface and for the control of aquatic plants growing beneath the water surface.
- Periods of treatment: Generally spring and late summer. Treatment after September 1 may require special authorization.
- Dosage: Maximum application is two gallons (35.3% A.I. [inactive ingredient]) per surface acre of water.
- Treatment area: Shall not extend beyond 200 feet from shore or beyond a maximum depth of six feet, whichever gives the greatest distance from shore.

- Repeat treatments: No permit shall be issued for a second treatment within the same season.
- Water-use restrictions: Treated waters shall not be used for irrigation, bathing, fishing, or by man or animals for drinking or food processing for a period of 14 days after treatment.

Under 6 NYCRR Part 703.5, there is also a potable water use restriction standard of 20 µg/L established for diquat in waterbodies used as potable water sources (Class AA or Class A waterbodies) and for waterbodies upstream of potable water supplies (NYSDEC 2015). Chautauqua Lake is classified as a Class A waterbody (6 NYCRR Part 800.9 Table VI).

3.2.2.1 Mode of Action

Diquat is a contact herbicide (NYSDEC 2015; NYSFOLA 2009) that inhibits photosynthesis and rapidly destroys cell membranes (Netherland 2014; Ross and Childs 1996). The herbicide is not translocated to other parts of the plant due to the destruction of the cell membranes (Ross and Childs 1996).

3.2.2.2 Environmental Behavior and Fate in Aquatic Systems

The methods of loss in the aquatic environment is through adsorption (uptake by plants), photolysis (breakdown by exposure to sunlight, if used in a foliar application), and microbial degradation (when bound to organic matter) (Cooke et al. 2005). Diquat may also bind to clay particles, where it becomes biologically unavailable (Cooke et al. 2005). Higher turbidity can lead to very fast deactivation of diquat as the herbicide binds with negatively charged particles in the water column (Netherland 2014). The typical half-life of diquat ranges from less than a day to a week (Netherland 2014).

3.2.2.3 Relative Effectiveness, Typical Application Rates, and Timing of Application

As stated above, according to 6 NYCRR Part 327.6(b)(5) diquat treatment areas shall not extend beyond 200 feet from shore or beyond a maximum depth of six feet, whichever gives the greater distance from shore (NYSDEC 2015; NYSFOLA 2009).

Diquat is effective at controlling target plants along shorelines, in spot treatments, and in areas with high water exchange (Cooke et al. 2005). Eurasian watermilfoil has been found to be extremely susceptible to diquat under low turbidity conditions, even with reduced exposure times (Skogerboe et al. 2006). Poovey et al. (2002) found in a mesocosm study that diquat is also effective at controlling curly-leaf pondweed, and treatments resulted in reduced shoot and root biomass, and damaged turions.

Typical application rates used range from 0.1 to 0.37 parts per million (ppm) (Netherland 2014). The exposure time used for effective treatment is typically 12 to 36 hours (Cooke et al. 2005; Madsen 2000).

3.2.2.4 Potential Impacts to Non-Target Aquatic Plant Species
Diquat effects a wide variety of plants (WDNR 2018a), and, based on product labels, diquat effectively controls water lettuce (*Pistia stratiotes*), water hyacinth (*Eichhornia crassipes*), duckweed (*Lemna* spp.), *Salvinia* spp., pennywort (*Hydrocotyle* spp.), frogsbit (*Limnobium spongia*), cattails (*Typha* spp.), bladderwort (*Utricularia* spp.), pondweeds, coontail (*Ceratophyllum demersum*), elodea (*Elodea* spp.), and naiad (*Najas* spp.).

3.2.2.5 Additional Pros and Cons

Pros

- Limited toxicity to fish at recommended doses on label (Holdren et al. 2001)
- Rapid action (Cooke et al. 2005; Holdren et al. 2001)
- Limited drift (Cooke et al. 2005; Holdren et al. 2001)
- Effective in tank mixes with copper compounds (Madsen 2000)

Cons

- Sometimes toxic to zooplankton at recommended dosage (Holdren et al. 2001)
- Diquat has been shown to be toxic to young fish (NYSDEC 2015), and applications to waterbodies with stressed bass, walleye, and/or muskellunge populations may be limited (NYSFOLA 2009). The best way to mitigate for these fish impacts is to dilute and apply diquat as a surface spray (NYSDEC 2015).
- Inactivated by suspended particles; therefore, ineffective in turbid waters (Holdren et al. 2001)

3.2.3 Endothall
Dipotassium salt of endothall is the active ingredient in multiple formulations registered for use in New York State, including Aquathold G&C, Aquathol® K, and Aquathol® Super K. According to the product label, dipotassium salt of endothall is also found in combination with 2,4-D in another New York State-registered herbicide, Chinook®.

Under 6 NYCRR Part 703.5, there is a potable water use restriction standard of 50 µg/L established for endothall in waterbodies used as potable water sources (Class AA or Class A waterbodies) and for waterbodies upstream of potable water supplies (NYSDEC 2015). Chautauqua Lake is classified as a Class A waterbody (6 NYCRR Part 800.9 Table VI).

3.2.3.1 Mode of Action
Endothall is a contact herbicide that impacts target plant species at a slower rate than diquat and does not lead to a rapid plant die-off (NYSDEC 2015; NYSFOLA 2009). This aquatic herbicide impacts target plant species by inhibiting respiration and protein synthesis (Netherland 2014).

3.2.3.2 Environmental Behavior and Fate in Aquatic Systems
There are two formulations available for use in New York with different active ingredients: dipotassium salt of endothall (liquid and granular) and dimethylalkylamine salt of endothall (liquid and granular). The NYSDEC Bureau of Habitat recommends against the use of dimethylalkylamine salt of endothall in fish-bearing waters (NYSDEC 2015). The granular form of the dipotassium salt of endothall provides a slow release of the active ingredient with less impact on the water column (NYSDEC 2015).

The method of disappearance is plant metabolism and microbial degradation (Cooke et al. 2005), which is influenced by water temperature (Netherland 2014). The typical half-life of endothall ranges from two to 14 days (Netherland 2014). Endothall remains in the water column longer than other herbicides (e.g., diquat and 2,4-D); however; the breakdown products of endothall (carbon dioxide and water) are of less environmental concern than that of other herbicides (Cooke et al. 2005; NYSFOLA 2009).

3.2.3.3 Relative Effectiveness, Typical Application Rates, and Timing of Application
Endothall is effective along shorelines, in spot treatments, and in areas with high water exchange (Cooke et al. 2005). Since endothall does not kill plant root systems, plants may recover following treatment (Holdren et al. 2001). Endothall is applied at application rates of 1.5 to 3.0 ppm for curly-leaf pondweed control and 3.0 to 4.0 ppm for Eurasian watermilfoil control (NYSDEC 2015). The exposure time used for effective treatment is typically 12 to 36 hours (Cooke et al. 2005; Netherland 2014).

Extensive field studies have shown that endothall is an especially effective (Madsen et al. 2002; Skogerboe and Getsinger 2002, 2006; Skogerboe et al. 2008; Johnson et al. 2012) and somewhat selective control of curly-leaf pondweed (Parsons et al. 2004; Skogerboe and Getsinger 2001, 2002). A study of early season curly-leaf pondweed spot treatments in Minnesota lakes found that the herbicide substantially reduced (but did not eliminate) the target species frequency and biomass in May and June for each year of treatment (Johnson et al. 2012). In lakes treated with endothall for two or more consecutive years there were cumulative reductions of curly-leaf pondweed frequency during point-intercept aquatic vegetation surveys (Johnson et al. 2012). Turion abundance also declined substantially during the first two years of treatment but slowed in subsequent treatment years. It was therefore hypothesized that the viable turions that remained in the lakes were produced prior to the herbicide treatments, as the results suggest that the most viable and shallow buried turions were eliminated during the first two years of treatment, leaving the deeper buried and potentially less viable turions in the sediment bank (Johnson et al. 2012).

3.2.3.4 Potential Impacts to Non-Target Aquatic Plant Species
Endothall is most often used to control coontail, Eurasian watermilfoil, and most pondweeds (NYSFOLA 2009), so if used there may be impacts to coontail and

the native pondweed species. In a mesocosm study, Skogerboe and Getsinger (2002) found that when applied at low concentrations (0.5 to 1.0 mg/L), Illinois pondweed (*Potamogeton illinoensis*), sago pondweed (*Potamogeton pectinatus*), and wild celery (*Vallisneria americana*) were injured by endothall but not killed and showed signs of recovery at eight weeks post-treatment. A study of early season curly-leaf pondweed spot treatments with endothall in Minnesota lakes found that the treatment did not have an overall negative impact on native aquatic macrophytes (Jones et al. 2012).

3.2.3.5 Additional Pros and Cons

Pros

- Rapid action (Cooke et al. 2005; Holdren et al. 2001)
- Limited drift (Cooke et al. 2005)
- Not affected by particulates of dissolved organic material in water column (Madsen 2000)

Cons

- May be toxic to aquatic fauna, degree of toxicity is dependent on formulation (Holdren et al. 2001)
- Use restrictions for water supply, agriculture, and contact recreation following treatment (Holdren et al. 2001; NYSDEC 2015)

3.2.4 Florpyrauxifen-benzyl

Florpyrauxifen-benzyl is a new aquatic herbicide, first registered with the United States Environmental Protection Agency (USEPA) in 2017 (WDNR 2018b). The herbicide was registered for use in New York State in 2019 (NYSDEC 2019), and the only available formulation is for a liquid form of the herbicide called ProcellaCOR EC™ (WDNR 2018b).

3.2.4.1 Mode of Action

Florpyrauxifen-benzyl is a systemic herbicide that is part of a new class of synthetic auxins, the arylpicolinates, which have a different binding affinity from other auxin mimics (NYSDEC 2019; Ecology 2017; WDNR 2018b). This aquatic herbicide causes excessive elongation of plant cells, leading to atypical growth and fragility of leaf and shoot tissue (within a few hours to days following treatment), ultimately resulting in plant death (within two to three weeks following treatment) (WDNR 2018b).

3.2.4.2 Environmental Behavior and Fate in Aquatic Systems

Florpyrauxifen-benzyl degrades through multiple pathways including photolysis, aerobic aquatic degradation, and hydrolysis into hydroxyl, benzyl-ester, and acid metabolites (Ecology 2017). The half-life ranges from less than a day to six days, depending upon the degradation pathway (NYSDEC 2019). Compared with endothall, 2,4-D, and triclopyr, florpyrauxifen-benzyl persists for a shorter period of time in water (Ecology 2017).

3.2.4.3 Relative Effectiveness, Typical Application Rates, and Timing of Application

According to the ProcellaCOR EC product label, the herbicide is designed for use in slow-moving waterbodies including ponds, lakes, and reservoirs. Florpyrauxifen-benzyl is most effective if applied to actively growing plants, as mature plants may require a higher concentration and longer contact time for control (WDNR 2018b). Exposure time for effective control is 12 to 72 hours, depending on the concentration used and the target species (Ecology 2017). Plant death typically occurs within 2 to 3 weeks of the herbicide application (WDNR 2018b).

Control of Eurasian watermilfoil can be achieved at in-water spot/partial treatment rates of 10 to 50 micrograms per liter (µg/L), which is lower than other registered herbicides (Ecology 2017).

3.2.4.4 Potential Impacts to Non-Target Aquatic Plant Species

Florpyrauxifen-benzyl has shown high selectivity for use on Eurasian watermilfoil (and hydrilla [*Hydrilla verticillata*]), with limited impacts to native aquatic plants including bulrushes (Cyperaceae), cattails, pondweeds, and naiads (Ecology 2017). Tolerance of native aquatic plants has been demonstrated in growth chamber and mesocosm studies (Netherland and Richardson 2016; Richardson et al. 2016) and in government and university research (Ecology 2017).

3.2.4.5 Additional Pros and Cons

Pros

- The USEPA granted florpyrauxifen-benzyl *Reduced Risk* status in early 2016, based on the environmental and toxicological profiles as compared to currently registered herbicides, with the reduction in risks to human health as the main driver behind this determination (Ecology 2017).
- There are no restrictions for recreational uses (NYSDEC 2019).
- There are no set-back requirements for potable water intakes, but concentrations cannot exceed the generic New York State drinking water standard of 50 µg/L (NYSDEC 2019).
- Through acute and long-term ecotoxicological testing (using concentrations higher than those outlined on the label), this herbicide has been shown to be nearly non-toxic to birds, mammals, and fish species (Ecology 2017).
- Provides a new mode of action, which can help prevent development of herbicide resistance if used in rotation or combination with other herbicides (Ecology 2017).

Cons

- There are restrictions on the use of treated water for irrigation and watering livestock (NYSDEC 2019). For irrigation treated water can be used once the concentration of florpyrauxifen-benzyl is below two parts per billion (ppb) (measured using FasTEST), or can follow the precautionary waiting periods outlined on the ProcellaCOR EC label (six hours to 35 days, depending on percent of waterbody treated and concentration) (ProcellaCOR EC Label).

- Do not compost plant material from treated area (ProcellaCOR EC Label)
- Has been only tested against a selection of native aquatic plant species to date (NYSDEC 2019).

3.2.5 Flumioxazin

Flumioxazin is the active ingredient in multiple formulations registered for use in New York State, including Clipper®, Clipper® SC, Flumigard™, Pond-Klear™, Propeller™, Schooner™, and SureGuard® SC. According to the product label, flumioxazin is also found in combination with 2,4-D in another New York State-registered herbicide, Depth Charge™.

3.2.5.1 Mode of Action

Flumioxazin is a contact herbicide also used as an algaecide (Ecology 2017). This herbicide blocks chlorophyll biosynthesis through the formation of peroxides, which inhibits a plant-specific enzyme and damages cell membrane function and structure causing rapid desiccation and necrosis after exposure to sunlight (Ecology 2017; Netherland 2014).

3.2.5.2 Environmental Behavior and Fate in Aquatic Systems

Flumioxazin has a typical half-life of minutes to days, dependent upon water pH (Netherland 2014). Although little information is available regarding flumioxazin breakdown products, the available information suggests that the breakdown products may be less toxic than flumioxazin itself (Ecology 2017).

3.2.5.3 Relative Effectiveness, Typical Application Rates, and Timing of Application

The water pH in the treatment area strongly effects the efficacy of flumioxazin as the herbicide degrades rapidly if water pH is 8 or higher (Netherland 2014; Ecology 2017). Flumioxazin is also most effective when applied early in the growing season when there is high light penetration in the littoral zone and to young, actively growing plants (Ecology 2017).

Typical submersed application concentrations range from 50 to 200 ppb (Netherland 2014), and product labels call for an initial concentration of 200 to 400 ppb. The exposure time required for effective control is typically from several hours to more than one day, with rapid onset of plant injury (Netherland 2014).

According to the Texas A&M AquaPlant diagnostic tool (n.d.), flumioxazin is a good control for both Eurasian watermilfoil and curly-leaf pondweed.

3.2.5.4 Potential Impacts to Non-Target Species

Flumioxazin is an effective control of several native plant species, including spatterdock (*Nuphar* sp.), water lily (*Nymphaea* sp.), and American lotus (*Nelumbo* *lutea*) (Netherland 2014), and according to the product labels for use in New York, it also controls coontail, duckweed, fanwort (*Cabomba caroliniana*), sago pondweed, variable-leaf pondweed (*Potamogeton diversifolius*), and variable-leaf watermilfoil (*Myriophyllum heterophyllum*).

3.2.5.5 Additional Pros and Cons

Pros

- The USEPA determined that flumioxazin has low potential to pollute the environment or cause non-target toxicity (Ecology 2017).

Cons

- Repeated use of flumioxazin without incorporating the use of other herbicides (in rotation or in combination) can lead to herbicide resistance in the target plant species (Ecology 2017).
- Flumioxazin is a contact herbicide. Contact herbicides are often more acutely toxic to other aquatic organisms (Ecology 2017).
- Product labels identify that there is a five-day use restriction for irrigation on food crops.

3.2.6 Fluridone

Fluridone is the active ingredient in multiple formulations registered for use in New York State, including Avast!® SC, Sonar® AS, Sonar® Genesis, Sonar® H4C, Sonar® PR, Sonar® Q, Sonar® SRP. The following restrictions for fluridone use for control of aquatic plants in New York state are presented in 6 NYCRR Part 326.2(b)(4):

- Applications of aqueous suspension formulations are permitted in waters of the State at application rates not to exceed 50 parts per billion. Swimming is not allowed in treated areas for a period of 24 hours following the application.
- Applications of pellet formulations are not permitted in waters less than two feet deep. The use of pellet formulations in waters less than two feet deep may be authorized for the control of invasive species. This use will be authorized by the issuance of an article 15 permit and the pellet formulations shall only be applied in accordance with label and labeling directions or as modified and approved by the Department of Environmental Conservation.

3.2.6.1 Mode of Action

Fluridone is a systemic herbicide (NYSDEC 2015; NYSFOLA 2009) that disrupts the synthesis of phytoene desaturase (a plant-specific enzyme that protects chlorophyll) (Netherland 2014) and, therefore, is not directly toxic to aquatic fauna if applied at the permitted concentrations (NYSDEC 2015). Without the protective enzyme, chlorophyll is destroyed in new plant growth giving the plant a bleached appearance, and the continued bleaching ultimately depletes the plant's carbohydrate reserves, leading to plant death (Netherland 2014). Actual plant death may take months following the initial treatment (Netherland 2014).

3.2.6.2 Environmental Behavior and Fate in Aquatic Systems

The primary degradation pathway for fluridone is photolysis (Cooke et al. 2005; Netherland 2014). Other causes of loss are microbial degradation (particularly in bottom sediments) and adsorption (Cooke et al. 2005). Fluridone degradation is influenced by water depth, water clarity, and season of application (i.e., day length) (Cooke et al. 2005; Netherland 2014). This herbicide may remain in the water column for three to nine months and in bottom sediments for four months to a year after application (Cooke et al. 2005).

3.2.6.3 Relative Effectiveness, Typical Application Rates, and Timing of Application

In New York, fluridone is used extensively to control Eurasian watermilfoil and curly-leafed pondweed (NYSFOLA 2009). Eurasian watermilfoil has been found to be more sensitive to fluridone at low dosages (Holdren et al. 2001). In field applications, this herbicide has effectively controlled curly-leaf pondweed (while also damaging native species) when the proper concentration exposure time is maintained (Turnage and Madsen 2017).

Fluridone is effective in small lakes and systems with low flow (Cooke et al. 2005). In field applications, fluridone was found to be less effective in areas of high water exchange (Madsen and Wersal 2008; Madsen et al. 2015). Effective control of Eurasian watermilfoil in protected sites has been found to be high (e.g., 93% reduction one-year post-treatment [Madsen et al. 2015]).

Effective treatment exposure time is dependent upon the target species, stage of plant growth, and time of year (Netherland 2014). Treatment timing and use rates dictate selectivity (Netherland 2104).

In order to be effective, concentrations must be maintained for a 30 to 90 day period (Cooke et al. 2005; NYSDEC 2015) and product labels call for a minimum of 45 days (Netherland 2014). Concentrations in the water column are monitored and measured periodically using FasTEST (an enzyme-linked immunoassay test), which is a rapid test that measures fluridone concentration in the water (NYSDEC 2015).

Granular formulations are preferred for partial lake treatments, as the conditions imposed upon liquid formulations do not apply to granular. FasTEST monitoring is still used to maintain the necessary lethal concentration. The granular formulation is still highly soluble in water, and although dissolution is a slow, it is difficult to contain the treatment within a small area (NYSDEC 2015).

Typical use rates of 5 to 30 ppb (Netherland 2014). Eurasian watermilfoil is particularly sensitive to fluridone and killed at concentrations as low as 6 to 8 ppb (NYSDEC 2015). For liquid applications, concentrations cannot exceed 50 ppb, and the sum of multiple applications cannot exceed 150 ppb, both of which are based upon the volume applied (NYSDEC 2015; 6 NYCRR Part 326.2(b)(4)(i)).

Application rates of 20 ppb are required within 0.25 miles of potable water intakes (6 NYCRR Part 326.2(b)(4)(i)).

3.2.6.4 Potential Impacts to Non-Target Aquatic Plant Species

At higher doses, such as in whole lake applications, fluridone is less selective and more likely to kill all aquatic vegetation (NYSDEC 2015). Fluridone is effective at controlling Eurasian watermilfoil, hydrilla, water hyacinth, water lilies (*Nymphaea* spp. and *Nuphar* spp.), and bladderworts, and typically does not impact native milfoils, coontail, naiads, elodea, and duckweeds (WDNR 2012a).

3.2.6.5 Additional Pros and Cons

Pros

- During the extended period of plant death, plants continue to provide structure for aquatic fauna and continue to produce oxygen (Holdren et al. 2001; Netherland 2014).
- Fluridone has low toxicity to aquatic fauna and humans, and is not known to be carcinogenic, oncogenic, mutagenic, or teratogenic (Holdren et al. 2001).
- Netherland (2014) lists that there are no use restrictions for potable water sources, fishing or swimming, however as noted above 6 NYCRR Part 326.2(b)(4) is more restrictive with regards to swimming in New York state following applications. Cons
- There are irrigation use restrictions (Netherland 2014; NYSDEC 2015).
- Extremely soluble and mixable and, therefore, difficult to use for partial lake treatment (Holdren et al. 2001)

3.2.7 Imazamox

Imazamox is the active ingredient in multiple formulations registered for use in New York State, including Clearcast® and Imox™.

3.2.7.1 Mode of Action

Imazamox is a systemic herbicide that disrupts the target plant's metabolism by targeting the plant-specific enzyme acetohydroxyacid synthase, which interferes with the synthesis of amino acids used in protein synthesis (Netherland 2014; NYSDEC 2015) and, therefore, is not directly toxic to aquatic fauna if applied at the permitted concentrations (NYSDEC 2015). Affected plants appear yellow or discolored immediately following application (BASF Corporation 2009) and new growth is stunted (Netherland 2014). Imazamox is more selective than fluridone (NYSDEC 2015). Imazamox is applied to the foliage, where it is absorbed and transported to the roots (NYSDEC 2015).

3.2.7.2 Environmental Behavior and Fate in Aquatic Systems

Imazamox is highly water soluble and dissociates in under a minute (BASF Corporation 2009). The main degradation pathway is photolysis, but degradation may also occur through microbial breakdown under aerobic conditions (BASF

Corporation 2009; Netherland 2014; NYSDEC 2015). Typical half-life under high-light conditions may range from 6.8 hours to 14 days or more (BASF Corporation 2009; Netherland 2014; NYSDEC 2015). If the application area does not receive continuous high-light conditions, the half-life is from 30 to 50 days from photolysis, microbial degradation, and dilution (NYSDEC 2015). Imazamox is persistent in the aquatic environment under anaerobic and low-light conditions, with a half-life of two or more years (BASF Corporation 2009). Imazamox degradation is also influenced by water depth, water clarity, and season of application (i.e., day length) (Netherland 2014).

3.2.7.3 Relative Effectiveness, Typical Application Rates, and Timing of Application

Imazamox is designed for use in ponds, lakes, reservoirs, and other slow moving or quiescent bodies of water (BASF Corporation 2009). Effective treatment exposure time is typically a minimum of 14 days (Netherland 2014). Target plants typically die within 4 to 12 weeks of the application and is most effective when applied while the plants are actively growing (NYSDEC 2015) and target macrophyte species are potentially killed within two applications (BASF Corporation 2009). Imazamox is typically applied at rates of 50 to 200 ppb, but can be applied as high as 500 ppb (NYSDEC 2015).

Sensitive aquatic plant species include Eurasian watermilfoil and curly-leaf pondweed, and dicots are generally less sensitive to imazamox (NYSDEC 2015).

While imazamox can be applied anytime within the growing season, it is suggested that it is most beneficial to apply early in the season during the active growing stages of Eurasian watermilfoil (BASF Corporation 2009), as Eurasian watermilfoil begins growing earlier and at colder water temperatures than native plants (Smith and Barko 1990).

3.2.7.4 Potential Impacts to Non-Target Aquatic Species

Other native pondweed species are sensitive to water column treatments include pickerelweed (*Pontederia cordata*), arrowhead (*Sagittaria* spp.), bulrush, and cattails are sensitive to surface treatments (BASF Corporation 2009).

3.2.7.5 Additional Pros and Cons

Pros

- There are no restrictions with respect to livestock watering, swimming, fishing, domestic use, or use of treated water for agricultural sprays (Netherland 2014; NYSDEC 2015).
- Imazamox is described by the USEPA as “practically non-toxic” to aquatic fauna, birds, and mammals (BASF Corporation 2009; NYSDEC 2015).

Cons

- There are some restrictions on the use of treated water for irrigation (Netherland 2014; NYSDEC 2015).

- Imazamox cannot exceed 50 ppb at potable water intakes, and may be applied at up to 500 ppb at a distance of 0.25 miles from an active intake (NYSDEC 2015).
- There has been limited use in New York to date (NYSDEC 2015).

3.2.8 Triclopyr

Triclopyr is available as both a granular and a liquid formulation (NYSDEC 2015) and is the active ingredient in multiple formulations registered for use in New York State, including Renovate 3®, Renovate OTF®, and Renovate LZR®. According to the product label, triclopyr is also found in combination with 2,4-D in another New York State-registered herbicide, AquaSweep®.

3.2.8.1 Mode of Action

Triclopyr is a systemic auxin mimic herbicide which mimics plant growth hormones, causing uncontrolled and disorganized growth, ultimately leading to plant death (Netherland 2014; NYSDEC 2015). Immediate impacts of auxin mimics to vegetation include bending and twisting of leaves and stems, and delayed symptoms include root formation on stems and abnormal roots, as well as misshapen leaves, stems, and flowers (Ross and Childs 1996).

3.2.8.2 Environmental Behavior and Fate in Aquatic Systems

The primary method of degradation is photolysis, with a potential half-life of less than one day (Netherland 2014; NYSDEC 2015). Other degradation pathways (i.e., microbial degradation [Netherland 2014]) are slower, and half-life typically ranges from three to five days, but the herbicide may be persistent at very low concentrations for longer (NYSDEC 2015). Field applications have observed low concentrations and rapid degradation of triclopyr in treated areas 24 hours post-treatment (Getsinger et al. 1997, as cited in Wersal et al. 2010; Getsinger et al. 2000; Poovey et al. 2004; Wersal et al. 2010). Triclopyr degradation is also influenced by water depth, water clarity, and season of application (i.e., day length) (Netherland 2014).

3.2.8.3 Relative Effectiveness, Typical Application Rates, and Timing of Application

Triclopyr is most effective in lakes and areas with low flow (Cooke et al. 2005). Typical use rate 0.25 to 2.5 ppm (submersed) (Netherland 2014) and the maximum application rate in New York is 2.5 ppm (NYSDEC 2015). Target exposure time is typically 12 to 60 hours (Cooke et al. 2005; Netherland 2014).

A highly selective herbicide, it is effective against Eurasian watermilfoil, purple loosestrife (*Lythrum salicaria*), and other aquatic dicots, with little to no effect on the more common monocots (Getsinger et al. 1997, 2000; Madsen et al. 2015; NYSDEC 2015; NYSFOLA 2009; Poovey et al. 2004; Wersal et al. 2010). Field applications have shown that triclopyr is not an effective control for curly-leaf pondweed, with instances of increased occurrence of the plant after triclopyr applications in waterbodies with other, more susceptible invasive plant species (Madsen et al. 2015).

3.2.8.4 Potential Impacts to Non-Target Aquatic Plant Species

The following monocots are sensitive to triclopyr: *Phragmites*, arrowhead, water hyacinth, American frogsbit, and water stargrass (*Heteranthera dubia*) (NYSDEC 2015).

3.2.8.5 Additional Pros and Cons

Pros

- Triclopyr is classified by the USEPA as "slightly to practically nontoxic" to aquatic fauna (NYSDEC 2015).
- For liquid formulation, no use restriction for recreational uses, fishing, fish consumption, and livestock watering (NYSDEC 2015)

Cons

- In deeper or turbid waters, photolytic degradation can be slow and triclopyr can persist at concentrations greater than 1 ppb for an extended period of time and may be carried downstream at concentrations greater than 1 ppb (NYSDEC 2015).
- Use restriction for irrigation with treated water until concentrations fall below 1 ppb or 120 days after application (NYSDEC 2015)
- There is a setback distance as indicated on product label from drinking water intakes, and if applied closer to an intake the intake must be turned off until the concentration in the immediate area is 50 ppb or less or 120 days after application (NYSDEC 2015).
- Additional use restrictions for fish consumption and contact recreation (if using granular formulation) (Holdren et al. 2001; NYSDEC 2015)

3.2.9 2,4-D

In New York, 2,4,-D is approved only for use on emergent and floating plant species, with the exception of Eurasian watermilfoil (a submergent species), which forms dense mats projecting above or laying at the surface and appears emergent at full growth (NYSDEC 2015; NYSFOLA 2009). There are numerous formulations available for 2,4-D, and the active ingredient for all is measured as the 2,4-dichlorophenoxy acetic acid equivalent (NYSDEC 2015). Formulations registered for use in New York State include Navigate® and Aquacide pellets. According to the product labels, 2,4-D is also found in combination with other herbicides in AquaSweep® and Chinook®, both discussed above.

The following restrictions for 2,4-D use for control of aquatic plants in New York state are presented in 6 NYCRR Part 327.6(c):

- Purpose: Authorized only for the control of emergent plants having a large part of their leafy growth projecting above or lying flat on the water surface;

- Periods of treatment: Restricted to late spring or early summer when the chemical is most effective;
- Dosage: Use of chemical solutions (i.e., liquid formulations) for dosage of up to eight pounds active ingredient per acre may be permitted in the treatment of dense stands. Use of pellets for subsurface application requires special authorization.
- Treatment area: The treatment area shall not extend beyond 200 feet from shore or beyond a maximum depth of six feet, whichever gives the greater distance from shore.
- Water use restrictions: Use of waters for irrigation shall be prohibited for a period sufficient to permit the decay of phytotoxicity (i.e., plant toxicity). The treated waters and those waters affected by the treatment shall not be used for other purposes during the treatment and for at least 24 hours thereafter.

Under 6 NYCRR Part 703.5, there is also a potable water use restriction standard of 50 µg/L established for 2,4-D in waterbodies used as potable water sources (Class AA or Class A waterbodies) and for waterbodies upstream of potable water supplies (NYSDEC 2015). Chautauqua Lake is classified as a Class A waterbody (6 NYCRR Part 800.9 Table VI).

3.2.9.1 Mode of Action

2,4-D is a systemic, auxin mimic herbicide, which acts as the naturally occurring plant hormone auxin that regulates plant growth (Netherland 2014; NYSDEC 2015; NYSFOLA 2009). This herbicide inhibits cell division in new plant tissue and stimulates growth in older plant tissue (Holdren et al. 2001).

3.2.9.2 Environmental Behavior and Fate in Aquatic Systems

While the primary method of loss is through microbial degradation into naturally occurring compounds, photolysis may play a role in more alkaline waters (Cooke et al. 2005; Netherland 2014). The typical half-life of 2,4-D ranges from four to more than 21 days (Netherland 2014) and 2,4-D is known to remain in sediments for up to several months after an application (Holdren et al. 2001; NYSFOLA 2009). Water temperature and microbial activity have been found to influence the rate of degradation (Netherland 2014).

3.2.9.3 Relative Effectiveness, Typical Application Rates, and Timing of Application

As stated above, according to 6 NYCRR Part 327.6(c)(5) areas treated with 2,4-D must be within 200 feet from shore or within waters shallower than six feet, whichever gives the greater distance from shore (NYSDEC 2015).

This herbicide is most effective in lakes and areas with slow water flow (Cooke et al. 2005). In general, typical submersed application rates are from 0.5 to 4 ppm (Netherland 2014). AquaKleen and Navigate are two granular products used in New York, with application rates of 100 to 200 pounds of formulated granular product per acre, consistent with guidance that granular formulations should not exceed 20 to 40 pounds of active ingredient (acid equivalent) per acre (NYSDEC 2015). Exposure time is typically 18 to 72 hours (Cooke et al. 2005).

In New York, use is restricted to late spring or early summer (NYSDEC 2015). It is important to treat plants using 2,4-D early in the season, during plant growth, but before vegetative propagules form because propagules (i.e., winter buds) may be unaffected by the treatment and can grow into new plants (Holdren et al. 2001).

Overall, field applications of granular 2,4-D indicate that the herbicide is an effective (88% control 5 weeks post-treatment [Wersal et al. 2010]; significant reductions [Bugbee and White 2004 as cited in Wersal et al. 2010]; >85% control 1 year post-treatment [Killgore 1984; Parsons et al. 2001]) and selective control of Eurasian watermilfoil with little to no damage to non-target plant species (Couch and Nelson 1982; Getsinger et al. 1982; Parsons et al. 2001; Wersal et al. 2010).

Field applications have shown that 2,4-D is not an effective control for curly-leaf pondweed, with instances of increased occurrence of the plant after triclopyr applications in waterbodies with other, more susceptible invasive plant species (Madsen et al. 2015).

3.2.9.4 Potential Impacts to Non-Target Aquatic Plant Species

The primary aquatic plant species controlled by 2,4-D are Eurasian watermilfoil, water chestnut, coontail, and water hyacinth (Madsen 2000; NYSFOLA 2009). 2,4-D does not typically affect pondweeds, wild celery, elodea, or hydrilla (Madsen 2000).

3.2.9.5 Additional Pros and Cons

Pros

- Relatively inexpensive (Cooke et al. 2005)
- Rapid action (Holdren et al. 2001)
- Moderately to practically non-toxic to birds in acute doses and non-toxic to amphibians at application rates (WDNR 2012b).

Cons

- Irrigation concerns
- May be toxic to aquatic fauna, degree of toxicity is dependent on formulation (Holdren et al. 2001). Ester formulations applied at application rates are toxic to fish and some aquatic invertebrates and studies have found evidence of endocrine disruption in amphibians (WDNR 2012b).
- Public perception (Cooke et al. 2005)
- Use restrictions for water for contact recreation and irrigation (NYSDEC 2015)

3.2.10 Conclusion

Based upon the summary of information provided above, for larger scale applications, a rotation of selective, systemic herbicides (such as florpyrauxifen-benzyl, imazamox, triclopyr, and 2,4-D) would lead to the least impacts to non-target aquatic plant species and aquatic fauna and effectively control Eurasian watermilfoil. Since these systemic herbicides are not as effective on curly-leaf pondweed, spot treatments with contact, broad-spectrum herbicides (such as endothall and flumioxazin) in vegetative beds with high densities of curly-leaf pondweed would effectively control this invasive species, but with some impacts to native pondweeds.

4 Best Management Practices

The following are a selection of typical BMPs that can be applied to the control of aquatic invasive and nuisance plant species.

Adaptive management is a commonly used technique, where management decisions and goals are periodically reevaluated as new information is collected, which allows for continual improvement of the management plan (NYSFOLA 2009). With regards to herbicide use for aquatic plant control, plant communities should be regularly monitored for herbicide efficacy and plant regrowth to best inform management decisions (Thum et al. 2017).

Integrated pest management (IPM) utilizes multiple management techniques for control of target nuisance species and not a singular management tool. Integrated plant management utilizes the most effective combinations of available physical, chemical, and biological management techniques and tools available (Ecology 2017; NYSFOLA 2009). Often this involves the use of a lake-wide treatment method (e.g., herbicide or mechanical harvesting) with a second aquatic plant management method capable of spot treating (e.g., hand-harvesting or benthic barriers) with preventative measures (e.g., boat launch stewards) (NYSFOLA 2009), as no one management tool or technique is sufficient for all scenarios (Madsen 2000). Integrated plant management programs are capable of incorporating new information (i.e., adaptive management) (Ecology 2017). When designing an integrated plant management program, it is highly important that compatible management techniques are employed. For instance, it is inefficient to stock a waterbody with an herbivorous organism and utilize mechanical harvesting as a primary method of management; one defeats the other (NYSFOLA 2009).

As introduced in Section 3.1 above, an effective BMP includes rotating herbicides, as overreliance on herbicides with a single mode of action leads to resistance (Aquatic Plant Management Society 2014; Hussner et al. 2016).

To reiterate from previous discussions, proper control of persistent aquatic invasive and nuisance plant species such as Eurasian watermilfoil through herbicides, needs to use consistent, repeated treatments to fully combat vegetative regrowth from root crowns, auxiliary shoot formation, and settled vegetative fragments, even following 2,4-D and triclopyr applications (Thum et al 2017).

Adaptive management, integrated plant management, herbicide rotation, and consistent herbicide treatments are all BMPs that should all be incorporated into Chautauqua Lake aquatic plant management plans. Further review of physical and biological aquatic plant management is needed to develop an appropriate combination of techniques for an integrated plant management strategy.

5 References

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